DRAFT STAFF REPORT
SUBMITTED FOR PEER REVIEW

CENTRAL VALLEY REGIONAL WATER QUALITY CONTROL BOARD

SPECIAL STUDY:

ASSESSMENT OF SEDIMENT DELIVERY FROM THE RUBICON JEEP TRAIL

APRIL 2009

1.0. INTRODUCTION

A growing body of literature suggests that OHV trails are sources of chronic erosion (Wilshire et al., 1978; Sack and da Luz, 2003; Welsh et al., 2008). Although there is a paucity of data regarding beneficial use impairments from OHV trails, there is abundant evidence that unpaved roads are capable of increasing turbidity and suspended sediment concentrations, altering channel substrate and morphology, and adversely affect water quality (Cedarholm et al., 1981; Bilby et al., 1989; Waters, 1995). While the magnitude of accelerated surface erosion is often much less than that of episodic erosion processes (i.e., mass wasting), aquatic species may not be adapted to high frequency, low magnitude disturbance (Luce and Black, 2001).

The following assessment is to determine the relative magnitude of water quality impacts from off-highway vehicles (OHVs) on the Rubicon Jeep Trail (RJT). The assessment was prompted by stakeholder complaints and by field observations from Regional Board employees. Stakeholder complaints included a wide variety of concerns, including water quality impacts from excessive sediment, human waste, and from petroleum leaks/spills. Field observations confirmed that the RJT is a source of sediment to waters of the state. However, the magnitude of the water quality impacts is generally unknown. The focus of this assessment is on erosional impacts from the RJT, as the relative magnitude of these impacts can be assessed through rapid assessment. Hence, the objectives of this assessment were to:

1. Estimate the order of magnitude of sediment production from portions of the Rubicon Jeep Trail;
2. Estimate the order of magnitude of sediment delivery from portions of the Rubicon Jeep Trail that are hydrologically connected to stream channels; and
3. Determine the relative impacts of trail derived sediments on the beneficial uses of water.

OHV trails exhibit similar erosion processes to unpaved roads, and this allows us to apply some of our understanding of road surface erosion processes to OHV trails (Welsh, 2008). To determine the order of magnitude of sediment production and delivery on the RJT, we use a modification of Megahan's (1974) negative exponential model for surface erosion over time. While the model was originally developed for steep granitic hillslopes disturbed by road construction in the Idaho Batholith, the general form of Megahan's model (i.e., negative non-linear decline) has been validated for road erosion across various lithologies and climates, and roads subjected to various forms of disturbance (i.e., new construction, traffic, and grading) (Luce and Black, 2001; Ziegler et al., 2001; 2002; Ramos-Scharrón and MacDonald, 2005). The Megahan model has also been loosely coupled with numerical surface erosion models (i.e., KINEROS2) to improve predictions of surface erosion over hourly time scales (Ziegler et al., 2002). We use concepts proposed by Ziegler et al. (2002) to modify the Megahan model so that it explicitly considers the presence of an erodible layer of loose sediment generated by traffic on the trail. We also explore the relative impacts of trail derived sediments on the beneficial uses of water by measuring and comparing surface grain size distributions above-and-below where the RJT crosses the fish-bearing Ellis Creek.

Given that this rapid assessment predicts the order of magnitude of sediment production and delivery from the RJT, it is important to place these estimates into proper context. While a rapid assessment will not necessarily provide an accurate estimate of the true magnitude of sediment production, it will provide information to determine whether the magnitude of sediment production and delivery is small [e.g. bucketful(s) of sediment], moderate [e.g. dump truck(s) worth of sediment], or large [e.g. hillslope(s) worth of sediment]. In turn, this relative estimate should assist Regional Board staff in determining whether erosional impacts meet the criteria of "significance" for impacts to the beneficial uses of water.

1.1. Background

Many studies have shown that sediment production rates from roads are very sensitive to the initial supply of easily erodible sediment on the road (Megahan, 1974; Reid and Dunne, 1984; Luce and Black, 2001; Ziegler et al., 2001; Ramos-Scharron and MacDonald, 2005). The literature indicates that the supply of erodible sediment is typically generated by activities such as road construction, traffic, maintenance (e.g. grading), or a combination of these variables. Traffic-induced increases in the supply of loose sediment can be attributed to soil detachment by tire traffic, in addition to crushing and churning forces that alter the trail surface's aggregate size distribution (Ziegler et al. 2001a).

Regardless of how the loose sediment layer is generated, most studies show that sediment production following disturbance is strongly time dependent. Sediment production rates are highest initially following disturbance, followed by a non-linear decline to a baseline rate (Megahan, 1974; Reid and Dunne, 1984; Luce and Black, 2001; Ziegler et al., 2001; Ramos-Scharron and MacDonald, 2005). Along the RJT we observed abundant evidence of a relatively deep, loose sediment layer on portions of the trail (see Figure 1). Since the sediment supply on the trail surface appears to be relatively high, we estimate the relative magnitude of sediment production from the RJT using Megahan's (1974) time dependent model for erosion following disturbance.

Surface erosion on a severely disturbed site can be described as (Megahan, 1974):

$$E_t = E_b + E_s \tag{1}$$

Where E_t represents the total erosion rate, E_b is the baseline erosion rate, and E_s is the erosion rate due to disturbance. E_b is related to erodibility of the underlying trail surface, ground cover, and the force applied to the disturbed surface by rainfall, overland flow, etc (Megahan, 1974). E_b can be relatively small when the surface is bedrock, consolidated, and/or armored because the trail surface can be resistant to the erosive forces of rainsplash and hydraulic erosion (Luce and Black, 1999; Luce and Black, 2001). However, E_b can be a substantial portion of total erosion when gullying, rutting, or extreme precipitation events occur (Ziegler et al., 2001a).

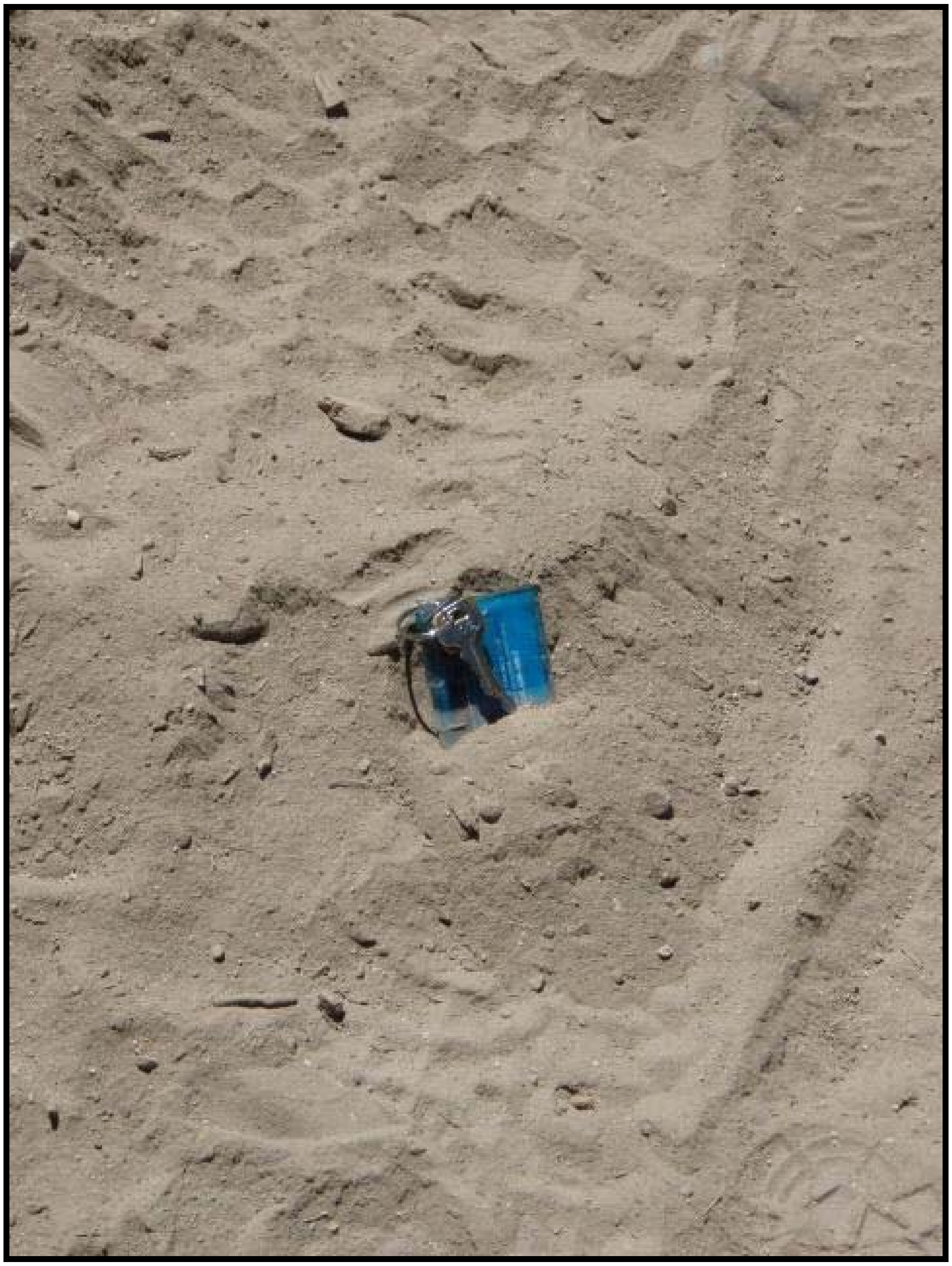

Figure 1. A close-up picture of the loose sediment surface layer along a portion of the Rubicon Jeep Trail. Keys are used for scale.

Megahan represented erosion E_s as a function of time where:

$$E_s = k\, S_o\, e^{-kt} \qquad (2)$$

where k is a rate constant (t^{-1}), S_o represents the mass or volume of sediment available for transport after disturbance, and t is time (t). Figure 2 illustrates the general form of the equation 2.

The rate constant (k) reflects how quickly the erosion rate recovers to the baseline rate. The k parameter can be relatively high if the loose surface sediments are transportable by relatively little runoff (e.g. uniform fine sand) (Luce and Black, 2001). S_o relates to characteristics of the disturbed soil body such as the particle size distribution (e.g. volume fraction taken by non-transportable soil particles such as rock fragments). S_o also relates to the transport capacity of runoff on the trail surface, as more erosive runoff can transport a greater proportion of the disturbed soil body (Luce and Black, 2001).

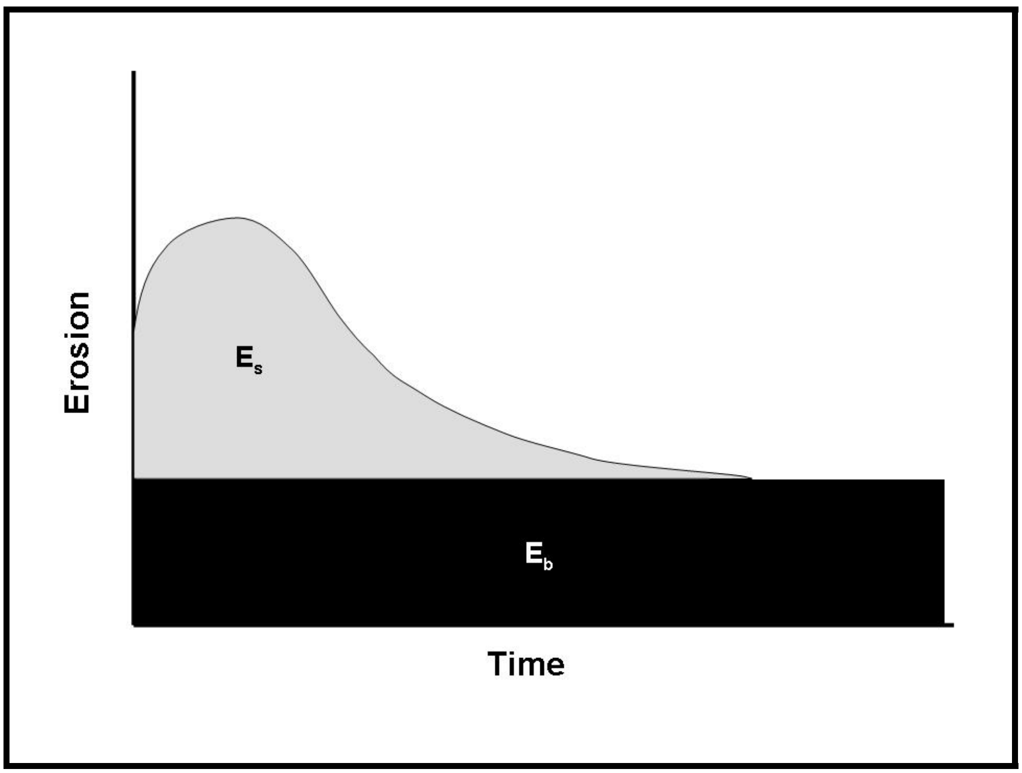

Figure 2. A conceptualized schematic of erosion following disturbance. Erosion increases quickly as the easily erodible sediment (E_s) is flushed from the disturbed surface. As the supply of erodible sediment is exhausted, the erosion rate decays to a baseline erosion rate (E_b). The area within the gray polygon represents the body of disturbed soil (S_o).

To represent sediment production for the first year following disturbance, equation 2 can be written as the following:

$$E_s = k\, S_o \qquad (3)$$

where k is an annual rate constant varying from 0.7 to 0.95 yr^{-1} for roads in the western United States (Megahan, 1974; Luce and Black, 2001).

Ziegler et al. (2002) represented S_o as a power function of pre-storm sediment availability (d_n; in kg m^{-2}):

$$S_o = d_n^{\beta} \tag{4}$$

where β is a fitted parameter greater than one[1]. The variable for sediment availability (d_n) can be measured through mass estimates of loose surface sediment on the disturbed surface (Ziegler et al., 2001b; 2002). For use in predicting sediment production from the RJT, we represent d_n by the following equation:

$$d_n = d_s A \tag{5}$$

where d_n is the volume of sediment available for transport, d_s is the depth of the loose sediment layer, and A is the area of the trail surface. By substituting equation 5 into 4, and 4 into 3 we arrive at the following approximation for erosion due to OHV traffic:

$$E_s = k (d_s A)^{\beta} \tag{6}$$

By substituting equation 6 into equation 1, assuming an annual rate constant based on the literature of 0.8 yr^{-1} (Megahan, 1974; Luce and Black, 2001), and assuming a more conservative linear relationship between S_o and d_n (i.e., $\beta=1$), we arrive at the final approximation of sediment production from an OHV trail following the first year of disturbance by OHV traffic:

$$E_t = E_b + 0.8(d_s A) \tag{7}$$

Equation 7 suggests that total erosion can be approximated by the depth of loose sediment on the trail surface. Equation 7 is supported by data from Thailand on small granitic road erosion plots subjected to simulated rainfall (Ziegler et al., 2001). Results from this study indicated that the measurement of the loose surface sediment provided almost one to one agreement with measured sediment production over 1-hour durations (Ziegler et al., 2001) (Figure 2). It is also supported over seasonal time scales by data from OHV trail segments on granitic soils in the Colorado Front Range (Welsh, 2008). The Colorado study showed that measurements of the loose surface sediment provided a reasonable approximation of measured sediment over a 6 month period over the summer and fall (Welsh, 2008) (Figure 3).

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2. Ziegler empirically derived the value of 1.42 for β.

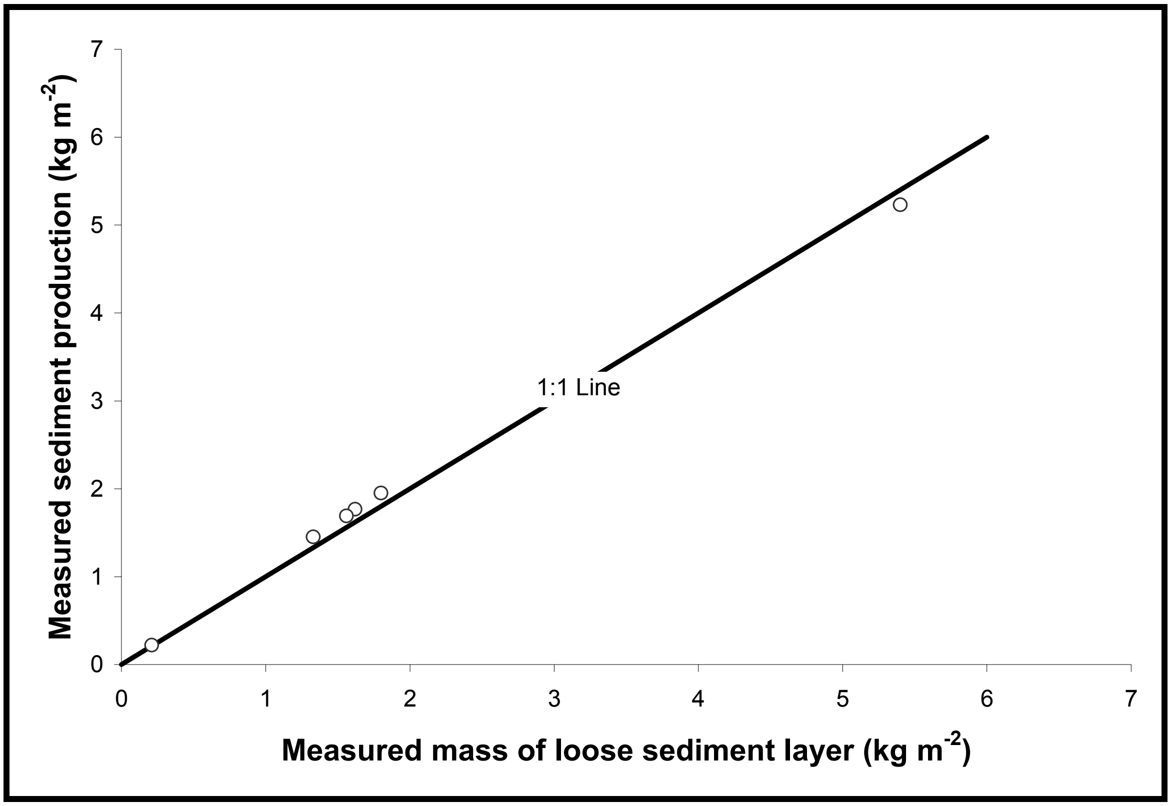

Figure 3. Observed sediment production versus the measured mass of the loose sediment layer for 6 road plots subjected to 1-hour duration simulated rainfall in northern Thailand (Ziegler et al., 2001b; 2002).

Based on the above theoretical framework and cited empirical evidence, we hypothesize that total annual erosion from an OHV trail segment can be approximated by volumetric measurements of the loose sediment on the trail surface. Figure 4 suggests that this approximation will result in a conservative underprediction of the actual erosion rate. An order of magnitude volumetric estimate of sediment production due to disturbance (E_s) can be achieved by estimating the depth of the of the loose sediment layer (d_s) on the trail surface and applying it to the surface area (A) of the trail segment. By estimating sediment production on hydrologically connected trail segments, we can provide an order of magnitude estimate of total sediment delivery to the channel network.

2.0. METHODS

Sediment production was estimated for a portion of hydrologically connected RJT segments. Trail segments were determined to be hydrologically connected when: 1) Trail segments discharged runoff and sediment directly into a stream at a trail-stream crossing; 2) Runoff and sediment from trail segments traveled diffusely across hillslopes and visibly delivered sediment to the stream channel; 3) Runoff and sediment from trail segments was discharged into gullies that were connected to the channel network; 4) Runoff and sediment from trail segments was discharged into unchanneled swales and visibly delivered sediment to the channel network; and 5) Low order stream channels were intercepted onto the trail and subsequently rerouted back into the channel network.

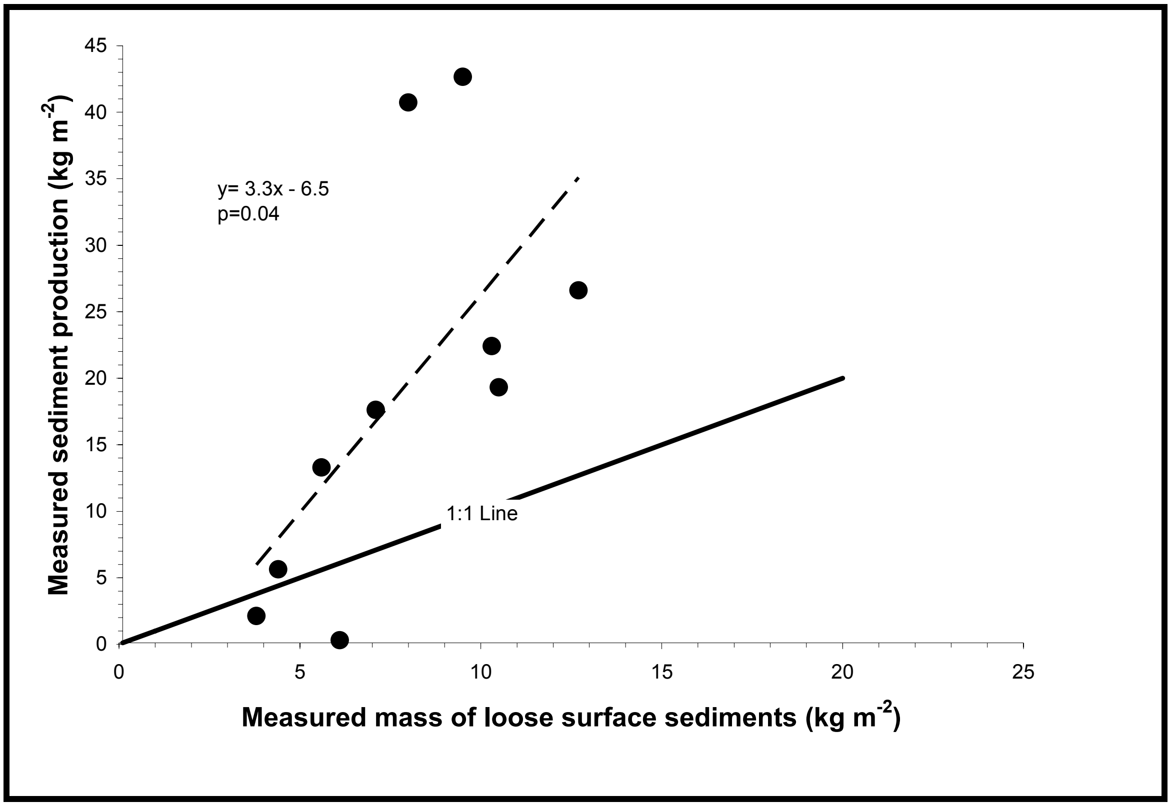

Figure 4. Observed sediment production versus the mass of the loose surface sediment layer for 10 OHV trail segments from the Colorado Front Range, USA. The regression equation indicates that measurements of the loose surface sediment underpredict actual erosion by more than a factor of three.

Volumetric sediment production (E_s) in cubic yards per year ($yd^3\ yr^{-1}$) was estimated for portions of the RJT that were visibly delivering sediment to the channel network by using the E_s term in equation 7:

$$E_s = 0.8(d_s\ A) \qquad (8)$$

The d_s variable was represented as a median depth of loose sediment obtained through random sampling along hydrologically connected road segments. Estimates of E_s were also calculated using the mean depth of loose sediment for comparison. However, the final rates are presented using the median depth.

To measure the trail segment area and loose sediment depth, the length (L) of the hydrologically connected road segment was first measured. Ten orthogonal transects were randomly selected for each 100 linear feet of trail by multiplying the trail length by a randomly generated number (i.e., 0<random number<1.0). At each orthogonal transect, the total trail width (W) was measured. Trail segment area was calculated by the following equation.

$$A = \left(\frac{\sum W_i}{n} \right) L \tag{7}$$

Along each orthogonal transect a point was randomly chosen between the total width of the trail to measure the depth of the loose sediment layer. A depth probe was inserted into the loose sediment until minimal resistance was encountered. Depth was recorded to the nearest 1/100th of a foot.

Sediment delivery was estimated for each hydrologically connected trail segment. Annual sediment delivery was assumed to 100% when the trail drained directly into the stream channel. For segments that did not directly drain into a stream channel (i.e., trail segments connected to the channel network via sediment plumes), sediment delivery was assessed using two scenarios: 1) no sediment delivery; and 2) 100% sediment delivery. These scenarios allow us to calculate a range of sediment delivery rates based on a best case scenario (i.e., 0% sediment delivery) and a worst case scenario (i.e., 100% sediment delivery).

Surface grain sizes were estimated above-and-below the Ellis Creek-RJT crossing to assess possible beneficial use impairment. Surface grain size distributions were estimated by performing random zig-zag pebble counts on Ellis Creek above-and-below where trail segment one crosses the creek (Bevenger and King, 1995) . While not an optimum procedure for larger channels, the zig-zag method is considered adequate for characterizing surface grain size distributions for smaller streams with poorly organized channel units (Schnackenberg and MacDonald, 1998). The pebble count extended at least 10 channel widths in length (i.e., reach scale) above and below the Ellis Creek crossing. A minimum of 100 clasts sampled both above and below the crossing. Variability for pebble counts was reduced by a gravel template (i.e., gravelometer), which bins grain size by phi (φ) classes, and by using the same observer above-and-below the crossing.

3.0. Results

3.1. Trail Segment Connectivity

Approximately 8 miles of the RJT were assessed for water quality impacts by Water Board staff in August of 2008 (i.e., 8/13-8/14; 8/26; 8/28). Seven trail segments were discovered to have some element of hydrologic connectivity to the channel network between Ellis Creek and the Rubicon River crossing near Buck Island Lake (Table 1). Connectivity was not assessed beyond the Rubicon River crossing. These 7 trail segments accounted for approximately 5485 feet of connected trail length, and approximately 1.9 acres of connected trail surface area (Table 2) (see field sketch in Appendix I).

Table 1. Mechanism of delivery for hydrologically connected trail segments.

Trail Segment	Comments	% Delivery to Channel Network
1	West (1A-1 through 1A-3) and east (1B) approaches to Ellis Creek crossing. Approaches drain directly into Ellis Creek.	100
2	First segment due east of Ellis Creek crossing. Approximately 900' of steeper trail (2A-2 and 2A-3) deposits much of its sediment in lower and flatter 200' of trail (2A-1). Sediment delivery to Ellis Creek via sediment plume across filter strip. Sediment plume is approximately 140' long and 8' wide. Subsegment 2A-1 intercepts small ephemeral channel.	0 &100
3	South (3A-1 and 3A-2) and north (3B) approaches to Rubicon River near Buck Island Lake. Approaches drain directly to the Rubicon River	100
4	Segments 4A and 4B drain to ephemeral channel approximately 0.5 miles east of Ellis Creek. Stream flows through meadow approximately 0.25 miles below trail, and eventually into Loon Lake. Much of sediment load is deposited within meadow.	0 &100
5, 6, 7	Segment 5, 6, 7 deliver sediment to ephemeral channel at FOTR stringer bridge. Segment 5 intercepts two smaller channels before draining into ephemeral channel below the FOTR bridge. Segment 6 includes approaches to FOTR bridge. Segment 7 drains to the ephemeral channel above the FOTR bridge.	100

3.2. Trail Sediment Production

Our estimate of sediment production is dependent on the depth of the loose sediment layer and trail surface area (equation 5). Loose sediment depth measurements were done for all surveyed trail segments with the exception of trail segment 7. Collectively, measured loose sediment depths ranged from 0 to 0.28 feet, with a median of 0.03 feet, a mean of 0.04 feet, and a coefficient of variation of 114 percent. Overall, the distribution of loose sediment depths was right skewed, indicating that the median loose sediment depth was a better indicator of central tendency than the mean. As a result, sediment production and delivery estimated were calculated using the median loose sediment depth for the each trail segment.

Surveyed trail segments cumulatively produced an E_s of 80 $yd^3\ yr^{-1}$ (1 significant figure (s.f.)). E_s values for the surveyed trail segments ranged from 1.7 to 19 $yd^3\ yr^{-1}$. The overall median loose sediment depth was used to calculate sediment production for trail segment 7, and the sediment production rate for this segment is estimated at 9.3 $yd^3\ yr^{-1}$.

Table 2. Measured trail segment characteristics used to calculate sediment production. Sediment production values for individual segments expressed to 2 significant figures. The total sediment production value is expressed with 1 significant figure.

	Length	Width		Loose Sediment Depth (ft)		E_s	
Segment	**(ft)**	**(ft)**	**Area (ft^2)**	**Mean**	**Median**	**Mean**	**Median**
1-A1	135	12.2	1647	0.04	0.02	1.9	1.0
1-A2	25	22	550	0.06	0.07	1.0	1.1
1-A3	26	38	988	0.04	0.04	1.2	1.2
1-B	105	12.9	1354.5	0.04	0.02	1.6	0.8
∑	**291**		**4540**			**5.7**	**4.1**
2-A1	190	15.5	2945	0.08	0.07	7.0	6.0
2-A2	300	14.1	4230	0.03	0.02	3.8	2.5
2-A3	634	16.5	10461	0.04	0.03	12.0	9.3
2-B	88	16.5	1452	0.03	0.02	1.3	0.9
∑	**1212**		**19088**			**24**	**19**
3-A1	98	16.6	1626.8	0.08	0.11	3.8	5.3
3-A2	326	13.8	4498.8	0.05	0.04	6.6	5.4
3-B	62	29.9	1853.8	0.08	0.11	4.4	6.1
∑	**486**		**7979**			**15**	**17**
4-A	400	13.6	5440	0.02	0	3.2	0
4-B	92	12.4	1140.8	0.06	0.05	2.0	1.7
∑	**492**		**6581**			**5.2**	**1.7**
5-A	276	13.8	3808.8	0.04	0.03	4.5	3.4
5-B	1221	14.3	17460.3	0.04	0.03	21	16
∑	**1497**		**21269**			**26**	**19**
6-A1	120	17.3	2076	0.04	0.04	2.5	2.5
6-A2	330	17.6	5808	0.05	0.02	8.6	3.4
6-B	182	12.7	2311.4	0.05	0.05	3.4	3.4
∑	**632**		**10195**			**15**	**9.3**
7	875	13.0	11375	0.04	0.03	14	10
∑	**875**		**11375**			**14**	**10**
TOTAL:	**5485**		**81027**			**100**	**80**

3.3. Sediment Delivery

Sediment delivery for trail segments 1, 3, 5, 6, and 7 is assumed to be 100 percent annually, since these trail segments discharge directly into the channel network. These trail segments deliver approximately 60 $yd^3\ yr^{-1}$ (1 significant figure) into the waters of the state. Trail segments 2 and 4 produce approximately 19 $yd^3\ yr^{-1}$ and 2.1 $yd^3\ yr^{-1}$, respectively, for a total of 20 $yd^3\ yr^{-1}$. However, these segments delivered sediment to the channel network via sediment plumes. Assuming that segments 2 and 4 do not deliver sediment to the channel network, we estimate an annual sediment delivery rate of 60 $yd^3\ yr^{-1}$ (1 s.f.). Assuming that segments 2 and 4 have 100% delivery, we estimate an annual sediment delivery rate of 80 $yd^3\ yr^{-1}$ (1 s.f.). Considering these two deliver scenarios, our approximation of total sediment delivery from the surveyed trail segments ranges from 60 to 80 $yd^3\ yr^{-1}$.

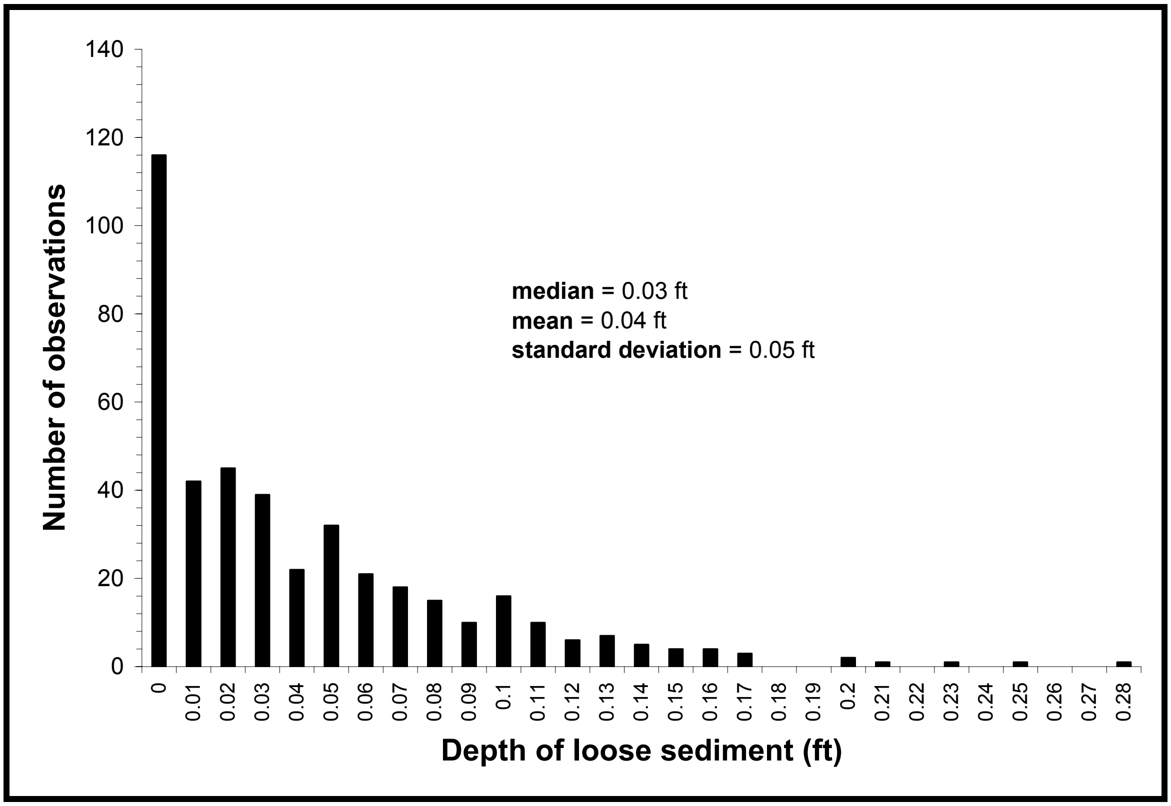

Figure 5. Histogram of measured loose sediment depths for hydrologically connected segments along the Rubicon Trail (n=421). A value of zero represents the absence of a loose sediment layer or the presence of bedrock.

3.4. Above-and Below Pebble Counts on Ellis Creek

Potential impacts to the Ellis Creek were assessed using pebble counts above-and-below the Ellis Creek crossing. Measurements indicated that the median surface grain size (D_{50}) above the Ellis Creek crossing was approximately 28.0 mm (n=108), as compared to a D_{50} of less than 5.0 mm below the crossing (n=129). In addition, the percent of sampled grains less than 2.0 mm in diameter increased from 13 to 31% below the crossing. The values for the D_{84} were approximately equal.

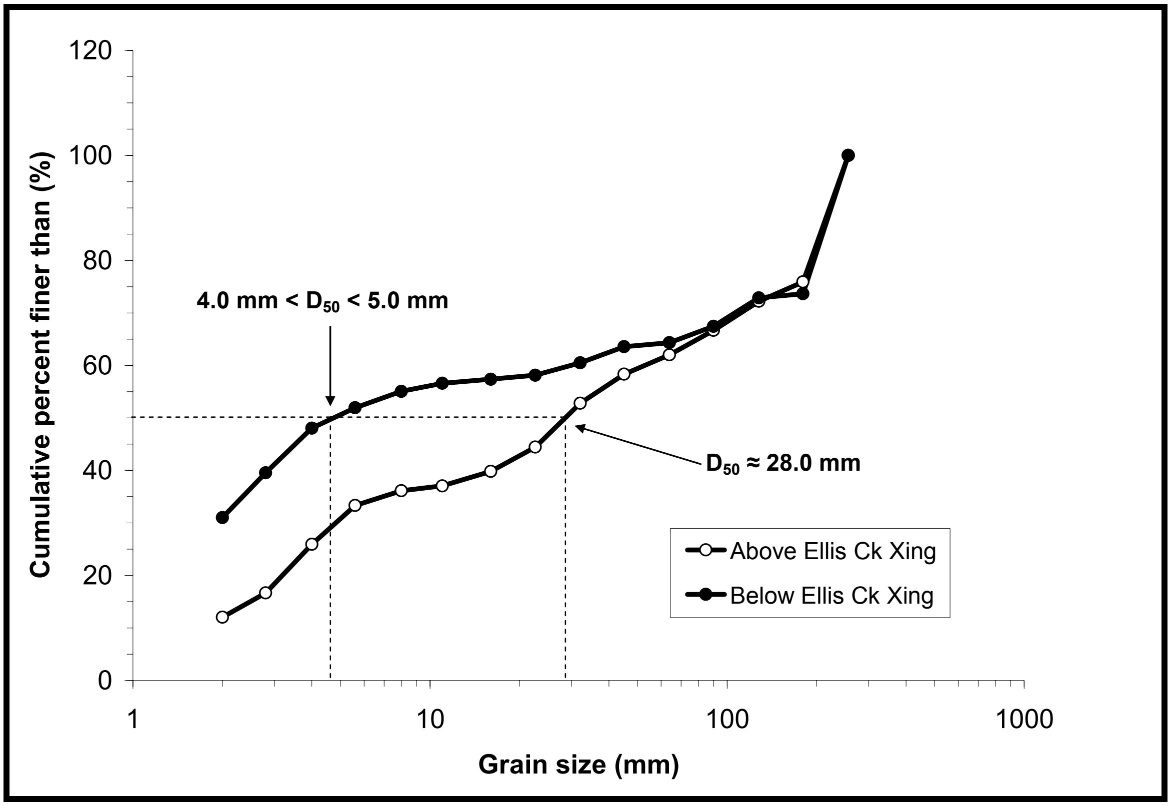

Figure 6. Surface grain size distributions above and below the Rubicon Trail - Ellis Creek crossing. The median grain size (D_{50}) below the crossing is approximately 1/6th the size of the D_{50} above the crossing.

4.0. Discussion

4.1. Comparison to Previous Studies

The estimated sediment production rates from the RJT were compared to sediment production rates from the OHV literature and to sediment production rates from native surface roads in the surrounding area. Assuming a bulk density of 1.2 Mg m^{-3} for very loose soils comprised of approximately equal parts coarse and fine soils (Haan et al., 1994 ; Figure 7.11), we estimated that the gravimetric sediment production rates from the RJT ranged from 3.4 – 28 kg m^{-2} yr^{-1}, with a mean value of 13 kg m^{-2} yr^{-1}. The estimated sediment production rate for the RJT is within the same order of magnitude as sediment production rates documented in other OHV studies (Wilshire et al., 1978; Sack and da Luz, 2003; Welsh, 2008), and an order of magnitude higher than sediment production rates from native surface roads in the South Fork American and Cosumnes river drainages (Coe, 2006). The Coe (2006) data is intended to represent an approximation of the baseline erosion rate, as Coe's rates generally reflect native surface roads subjected to light traffic and frequent drainage.

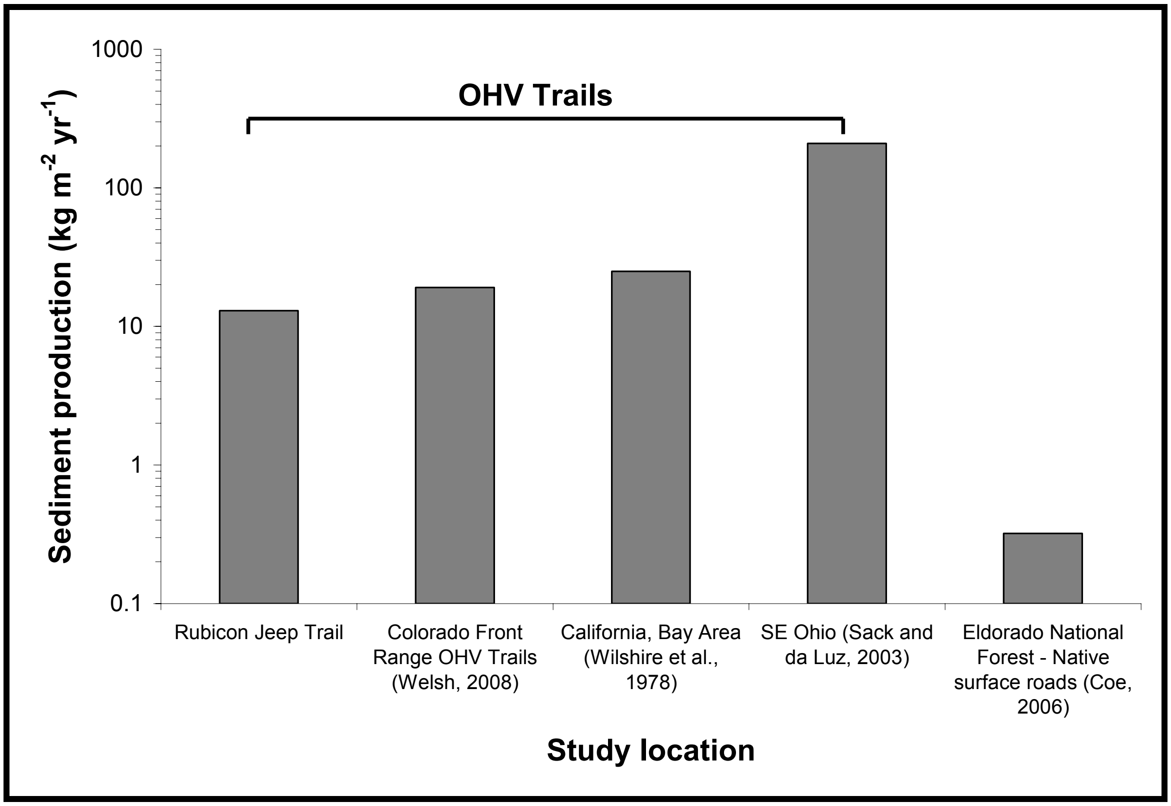

Figure 7. A comparison of the estimated mean annual sediment production rate from the Rubicon Jeep Trail versus other studies.

4.2. Assessment Assumptions and Accuracy of Estimates

The assessment of sediment delivery from the Rubicon Jeep Trail is dependent upon a variety of assumptions. The goal of this section is to determine whether the assessment assumptions affect the relative magnitude of the sediment delivery estimate.

The assessment assumes annual transport of 80% of the loose surface sediments from a trail segment, an assumption that is reflected in a rate constant of 0.8 yr^{-1}. The rate constant indicates the relative transportability of the loose sediment layer (Luce and Black, 2001). Luce and Black's (2001) data suggests a rate constant of approximately 0.7 yr^{-1} for basalt surfaced roads in the Tyee formation (i.e., sedimentary and metasedimentary rocks) of the Oregon Coast Range. The soils in this study were silty clay loams, the road segments ranged from 130– 390 feet in length, and slopes ranging from 3–13% (Luce and Black, 2001). Luce and Black's (2001) roads were subjected to grading of the road aggregate surface and grading of the native surface ditch. Megahan's (1974) data from the soils derived from quartz monzonite in the Idaho Batholith suggests a rate constant of 0.95 yr^{-1}. Megahan's rate constant was derived in coarse textured soils. Varying the rate constant between 0.7 to 0.95 yr^{-1} will adjust the absolute value of estimated sediment production rate, but will not affect the order of magnitude of the prediction.

The assessment does not take into account variations in rainfall and runoff erosivity. Consideration of these factors is important considering that the area surrounding the RJT has relatively abundant snowfall, and snowfall has minimal erosive force (Cooley et al., 1988). The elevation of the Rubicon Trail ranges from 5400-7000 feet (http://www.co.el-dorado.ca.us/rubicon/About.htm). The freezing level of winter storms in the Sierra Nevada usually fluctuates between 3300-8200 ft (Kattelmann, 1990), and this causes a corresponding fluctuation in the depth and extent of snow cover over time. While seasonal snow cover can potentially influence the erosive force applied to the trail surface by rainfall impact and runoff, the Rubicon Trail is not strictly subjected to snowfall during the winter season.

Results from Megahan (1974) provide additional insight into the potential for movement of loose erodible material in a snow dominated environment. Megahan's study area was characterized by winter snowfall and spring snowmelt, and has an identical R factor to the area surrounding the RJT (i.e., 10) (see Renard et al., 1997). Despite the dominance of snowfall, Megahan (1974) shows that approximately 80% of total erosion from his Deep Creek site occurred between November and June – a period dominated by less erosive snowfall and spring snowmelt. Furthermore, Megahan (1974) states that:

> "…these studies suggest that a widely used index of erosive forces (the erodibility index) was not well related to the time trends in erosion, at least during the initial period of rapid recession."

Luce and Black (2001) data suggest that rainfall magnitude was responsible for a two-fold variation in sediment production rates for roads that were freshly graded. However, the large interannual variability could be attributed to particularly large storm events.

Field observations of the trail segments indicate that there would be sufficient capacity to transport sediment following overland flow generation. The transport capacity of runoff down a trail segments is related to the length and slope of the trail (Luce and Black, 1999; Welsh, 2008), and the trail segments along the RJT commonly exceeds several hundred feet in length because of a lack of drainage structures. Segments 2A and 5B exceed 1000 feet in length. Given, that the RJT is subjected to both rainfall and snowmelt runoff and the fact that there is a lack of regular drainage long the trail, we believe there is ample transport capacity to move the loose sediment layer.

The model we used is very sensitive to the estimation of S_o, which is entirely dependent upon accurate characterization of the loose sediment layer. While it was beyond the scope of this study to assess the statistical rigor of our sampling approach, we did incorporate random sampling across the length and width of the trail. Our sample intensity (i.e., samples per length of road/trail) was greater than those employed by Welsh (2008) or Ziegler et al., (2001a), and these studies showed success in relating mass or volume of the loose sediment layer to sediment production. As a result, we do not expect sampling errors to affect the order of magnitude of the prediction.

The depth of loose sediment can potentially be related to the incision of the trail over time. Measurement of the loose sediment layer indicates that the median depth on the trail is 0.03 feet. If one assumes that the depth of loose sediment approximates the depth of erosion and that the depth occurs uniformly over time, then we can compare this rate with the depth of incision of the trail surface. Assuming that the RJT is 100 years old, the depth of erosion from our estimate would be approximately 3 feet. This is consistent with the observed depths of incision along soil mantled portions of the trail. This also indicates that our estimate is in relative agreement with conditions observed along the trail, and does not grossly overestimate the rate of erosion.

Our evaluation of trail connectivity is another potential source of error in the estimate of sediment delivery. Assessment of road drainage and road contributing areas is generally accurate to within +/- 30% when evaluation is done during the dry season (Montgomery, 1994). Given the potential for error with these types of evaluations, this should not affect the order of magnitude of our prediction.

4.3. Ellis Creek Pebble Count

Our estimate of sediment delivery from the approaches is approximately 4 yd yr^{-1}. Data from the pebble counts suggest that the approaches to the Ellis Creek crossing are causing a downstream fining of the substrate grain. Field observations below the crossing indicate a mantle of sediment with particles sizes similar to those found on the trail surface. While gradients for both reaches were similar, grain size fining may be in response to the higher frequency of pools and roughness elements in the reach below the crossing. However, there was a noticeable lack of fine sediment in the lee of roughness elements (e.g., boulders) in the reach above the crossing.

5.0. Conclusions

The Rubicon Jeep Trail (RJT) was assessed to determine the relative magnitude of sediment production and sediment delivery to waters of the state using a modification of Megahan’s 1974 model for erosion over time. The model was modified to explicitly consider the presence of an erodible, loose layer of sediment as per Ziegler et al. (2002). The Regional Board estimated that 7 surveyed trail segments were contributing an order of magnitude approximation of 60-80 yd^3 of sediment annually to waters of the state. However, this estimate is best viewed as having a potential range from 10 -100 yd^3 yr^{-1}. Estimated sediment production rates from the RJT are an order of magnitude greater than sediment production rates reported from lightly trafficked, well drained native surface roads on adjacent forest lands (Coe, 2006). The estimate is in order of magnitude agreement with OHV erosion rates from the literature. An above-and-below assessment of surface grain size distribution at the Ellis Creek trail crossing suggests that sediment from the trail surface may be causing a fining of the channel substrate.

6.0. References

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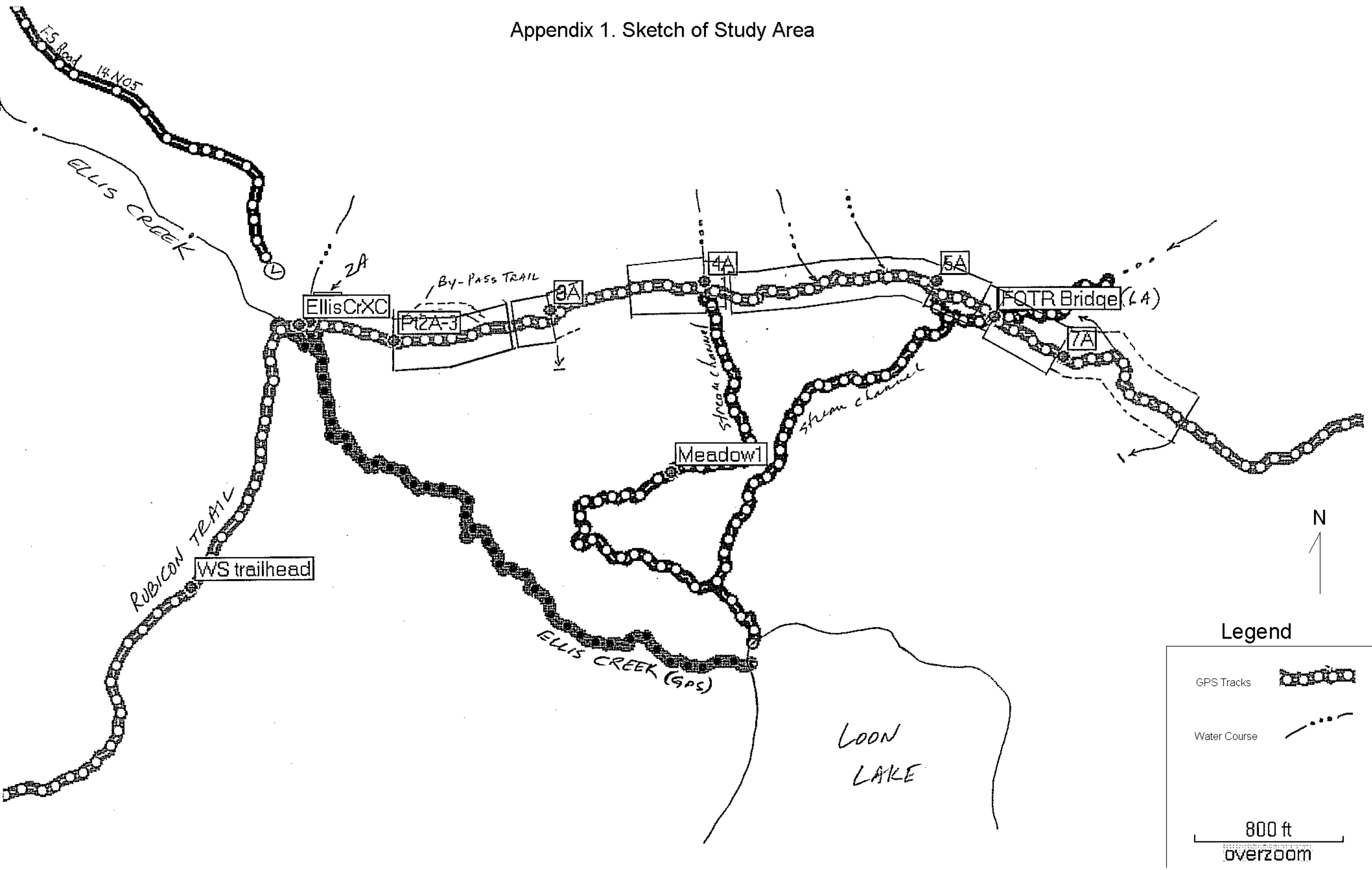
Appendix 1. Sketch of Study Area



Appendix II. Surface grain size data from Ellis Creek.

Table 1. Surface grain size data above the Ellis Creek-RJT crossing.

Grain size (mm)	Count
<2.0	13
2.0 to <2.8	5
2.8 to <4.0	10
4.0 to <5.6	8
5.6 to <8.0	3
8.0 to <11.0	1
11.0 to <16.0	3
16.0 to <22.6	5
22.6 to <32.0	9
32.0 to <45.0	6
45.0 to <64.0	4
64.0 to <90.0	5
90.0 to <128.0	6
128.0 to <180.0	4
≥180.0	26
Total:	**108**

Table 2. Surface grain size data below the Ellis Creek-RJT crossing.

Grain size (mm)	Count
<2.0	40
2.0 to <2.8	11
2.8 to <4.0	11
4.0 to <5.6	5
5.6 to <8.0	4
8.0 to <11.0	2
11.0 to <16.0	1
16.0 to <22.6	1
22.6 to <32.0	3
32.0 to <45.0	4
45.0 to <64.0	1
64.0 to <90.0	4
90.0 to <128.0	7
128.0 to <180.0	1
≥180.0	34
Total:	**129**